TECHNOLOGICAL ADVISORY COUNCIL NOISE FLOOR TECHNICAL INQUIRY DA 16-676, ET Docket No. 16-191

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Preamble:

In this filing we are responding to FCC TAC Noise Floor Technical Enquiry DA 16-191. We find the questions to be highly topical and important to ensure the smooth operation of wireless equipment and systems.

We submit our comments as independent research scientists working in the Institute for Networked Systems at RWTH Aachen University. RWTH Aachen University is a public university in Germany. For the avoidance of doubt, we stress that the comments are submitted as research scientists and do not imply any endorsement or opinion of RWTH Aachen University. We also state that the research we have conducted in relation to the noise floor is not sponsored by any commercial entity and only funding that has been received for any such research has been received from public sources.

Our comments are based in part on an on-going measurement campaign that we are conducting in Europe, the preliminary results of which have been reported in Palaios et al. [1], [2], [3]. While our own experience is from a European radio environment, we believe that our general conclusions are applicable also to the USA.

We are certainly happy to answer any inquires FCC TAC may have, and hope that our comments are helpful.

Question 1: Is there a noise problem?

The definitive answer on this depends on what one defines as “the problem” or more properly what is the accepted risk level that noise can cause degradation to the operation of wireless systems. We point out that a simple noise floor increase alone cannot be stated to be a problem, since for example satellite localization systems like GPS are more vulnerable to increased noise than, say, high power broadcasting.

With the above caveat, we believe that there exists a justified concern that noise can become a problem, and thus FCC should study the issue carefully. The increased noise (floor) can affect a number of different services, but we would like to point out especially the following important wireless services;

- **Satellite based navigation systems**, such as the Global Positioning System (GPS) and Global Navigation Satellite Systems (GNSS). Due to the weak signals level, these kinds of systems are particularly vulnerable for increased noise levels.
- **Cellular systems** should be also considered to be possibly vulnerable. While it is true that these systems in general have higher transmission powers, the aggregated noise at the cell boundaries can have detrimental effects to the quality of service.
- We also believe that various low-power sensing and emerging **Internet of Things (IoT)** devices might feel the effect, although here the evidence is weaker, partially due to the fact that this is still an emerging market and many devices are operating in crowded unlicensed bands.

The noise problem and where does it exist?

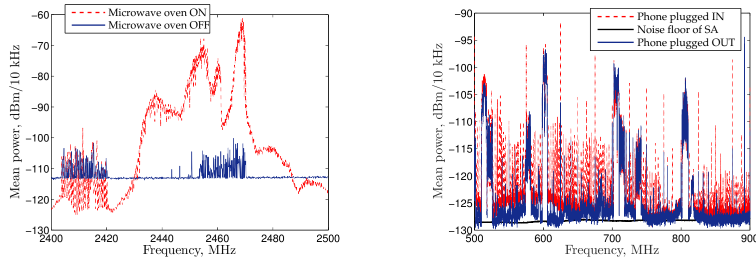
We note that many of the systems that are vulnerable to an increased noise floor, can be themselves also noise sources for other systems. A wide variety of devices can generate man-made noise, especially in the frequency bands up to 6 GHz. The possible sources include any transceiver equipment, electric motors, cars, LED and neon lights, and even everyday electric devices & consumer products through harmonics and intermodulation effects. Below we provide illustrative examples from our own measurements that are reported in our preliminary publications [1–3][1].

Electrical appliances

We present examples of devices that do not have transceiver components, since intuitively one would expect that transceiver chains are a major factor for emitted noise byproducts. We present in Figure 1 two examples of appliances that exist in most households and office environments. In Figure 1a, the noise pattern of a microwave oven is depicted during its operation in the ISM band. The microwave was at around 1 meter distance from the measurement platform. As one can see, the microwave oven emits byproducts that are spread over a span of around 60 MHz, over half of the ISM frequency band.

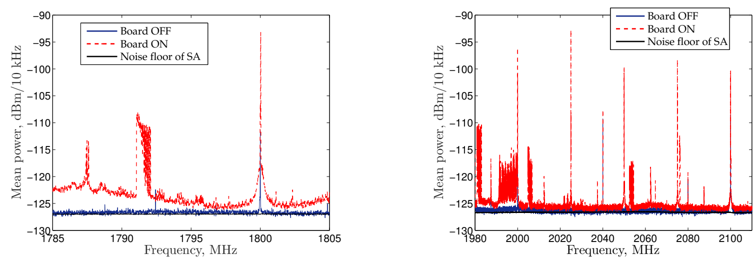
[1] There is a significant number of earlier prior art publications available, especially discussing the noise sources. We refer the reader to more recent papers from Wagstaff & Merricks [4], Achatz & Dalke [5], and older paper by Blackard et al. [6], and ITU report [7], and references there in. We are using our own examples, since they are very recent and done with equipment under our own control; we also consider various frequency bands up to 3 GHz.

The emitted power levels are quite high, reaching almost -60 dBm, well inside the operating ranges of today's networks. This is particularly serious for IEEE 802.11 based wireless systems as these rely on Listen-Before-Talk approaches.



(a) Microwave oven (b) Landline phone

Fig. 1: Results from various noise sources illustrated from indoor measurements.



(a) RF-passive circuit board: GSM1800 duplex gap (b) RF-passive circuit board: UMTS2100 duplex gap

Fig. 2: RF-passive circuit board as a noise source.

The second device is a landline phone depicted in Figure 1b. Noise characteristics here are different. Energy levels of noise are lower, but still at levels experienced by today's wireless services. The spread of noise vastly varies covering more than 400 MHz with narrow peaks that are spread all over that range. When the phone is powered on, a large number of narrowband peaks are visible in the presented frequency range, the bandwidth of which does not exceed 50 kHz. The noise floor is 5dB higher when the phone is turned on until a frequency of 650 MHz, after the which the effect is weaker.

Electronics with and without transceivers

We consider next devices that have some transmitter and receiver capabilities. For this example, we studied an RF-passive circuit board[2] with a transmitter front-end and a pair of car keys that both have transceiver components. Radio frontends tend to be non-linear and especially with cheaper consumer-devices these are inevitable RF byproducts. We start by showing how a typical overall suppression works with some examples in Figure 2, where the RF-passive circuit board noise byproducts are depicted. In Figure 2a, the duplex gap of GSM 1800 is measured where noise byproducts are present in the whole duplex gap. A very strong peak is visible at 1800 MHz with a power of -95 dBm. There is also a byproduct with a wide bandwidth at around 1792 MHz that has a bandwidth of 1 MHz.

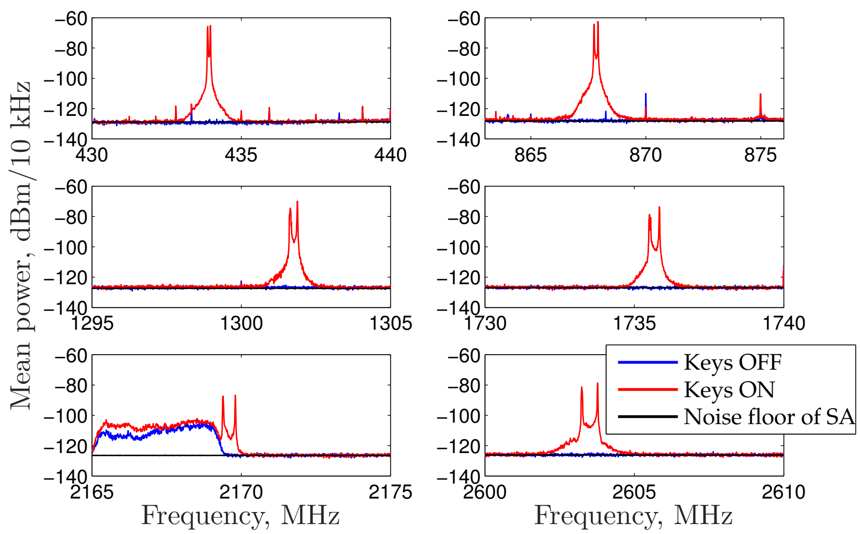


Fig. 3: An example of the car key noise profile.

[2] Our circuit board is a typical non-shielded electronics circuit board with simple components and power converter IC, but do not have any RF-components.

Low cost RF devices

Furthermore, we present how low cost RF devices can leak power into different frequency bands. We show the results for typically noisy byproducts of car keys in Figure 3. Here car keys were operated a few meters away from the spectrum analyzer. The allowed bands for the transmissions are presented in the figure as well, namely the 433.05 MHz-434.79 MHz and the 863 MHz-876 MHz bands. It is also visible that the car keys do not transmit only within the allowed bands, since we captured a lot of byproducts in different bands. These seem to be harmonics as they are located at multiples of the center frequency.

Question 2: Where does the problem exist?

Scientifically and strictly speaking there is a gap in our knowledge and precise answer cannot be given. We are not aware of any large-scale measurement campaigns that have covered a large geographical span with different environments (indoor, outdoor, residential vs. office etc.) with long measurement time periods. However, there is enough basic knowledge and limited measurements to provide a general overview, where future noise measurements should be conducted.

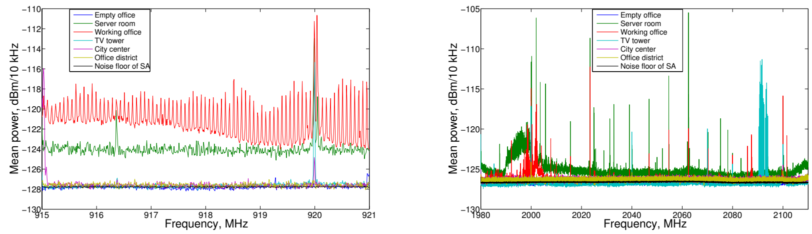
We point out that the noise problem should be considered both in the spatial and temporal domain. Thus one needs to consider different geographical locations, type of the location, and time of the day, before any deep conclusions can be drawn.

The spatial variety of the measured noise is high and depends on the location. There is a strong indication, also in our own measurements, that indoor noise can be as serious or even more serious that what is seen in many outdoor conditions. There is, of course, a difference between night and day – and we expect also that long-term measurements will reveal a cycle with weekdays. We are not aware of any such studies that have sufficiently long period data to study seasonality, and our own measurements do not have such, time-line either, yet.

In order to provide TAC members a general examples on what the spatial and temporal structures may look like, we provide the following examples.

Spatial variation

We present examples on the variability of noise across different locations. For this, we show results obtained in two different frequency guard bands, the GSM 900 and the UMTS for all measurement locations (indoor and outdoor). In Figure 4a the GSM 900 guard band is depicted. The overall noise at the occupied office room seems for that case to be the strongest with the working



(a) GSM 900 guard band for different measurement locations.

(b) UMTS guard band for different measurement locations.

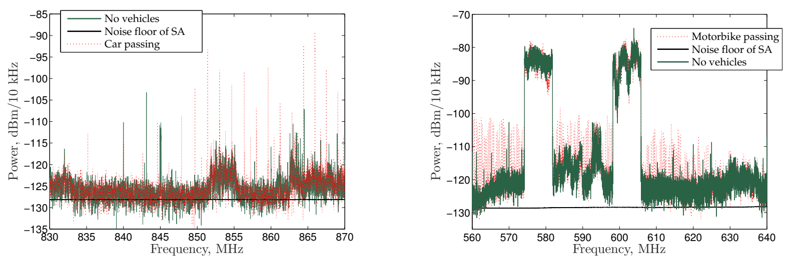
Fig. 4: The existence of noise at different measurement environments.

office coming second. From Figure 4a, it is clear how noise can be different at different locations. For example, at 915 MHz there is only a strong peak at the city center outdoor measurement location and apart from that the band is rather empty of noisy byproducts. It is also interesting that, even though all other measurement locations do not show any large noise byproducts still four of them exhibited a strong constant peak at around 920 MHz that looks to be dominant in the large coverage area where half of our indoor and outdoor measurement points were located. The noise components have not only variations in the time domain. We also note that while some noise components are highly localized, disappearing within tens of meters, others remain strongly visible within the range of hundreds of meters.

In Figure 4b the UMTS guard band is depicted. In comparison with the GSM 900 band the server room had the strongest noise byproducts with the office room coming second. UMTS band noise tends to be more sporadic with stronger power compared to the more spread out noise at the GSM 900 guard band. In the UMTS guard band also a strong noise component around 2090 MHz was found at the TV tower measurement location. As can be seen from these plots the noise varies widely in different locations and bands. Finally, it is also interesting to note how the noise level of the empty office room is. This is a strong indicator of how much noise is emitted from today's electronic devices that are part of a typical noise environment with active humans.

Temporal variation

We highlight the stochastic nature of noise presence at a receiver as this depends on the dynamics of noise sources around it. We present such an example in Figure 5. Figure 5a illustrates the noise generated by a car passing at a few meters distance from our measurement device. As the car passes, it generates narrow peaks of noise reaching up to -85 dBm. Similar behavior was also captured for a passing motorcycle where peaks were more densely packed at the first frequencies captured (as shown in Figure 5b), with peaks reaching up to -100 dBm. From our measurements, large variability was found between different car and motorcycle models on emitted noise patterns. The man-made noise is not only spatially but also temporally distributed.



(a) Passing car

(b) Passing motorcycle

Fig. 5: Examples of noisy byproducts created by different vehicles observed during the measurement campaign.

Evidence of noise

We continue by looking at the measurements we have collected in the indoor environment. We start by presenting the specific measurements we conducted in a server room, a room full of electronic boards and fans that are considered typical noise sources. Figure 6 depicts the measurement span of 20 MHz – 2500 MHz to show how the interference such noise sources can create. Even though Figure 6 contains licensed bands and one can not be exactly sure which of the energy measurements correspond to the licensed transmissions and which to the noise coming from the server room, it is still clear how much wide band noise is created from the server room. This is more clearly seen at the band around 1150 MHz – 1250 MHz.

Special note on noise characteristics

Traditionally research community has considered that noise floor levels are generated from thermal noise and man-made noise in terms of (Additive) White Gaussian Noise (AWGN) and some impulse noise components.

Based on the recent measurements we strongly advise that any future work should also readdress this issue with precision measurements. Assuming that the noise can be mainly assumed to be AWGN might not be safe in all the bands, and it would be highly important to consider not only the noise floor levels but general statistical structure of the noise floor.

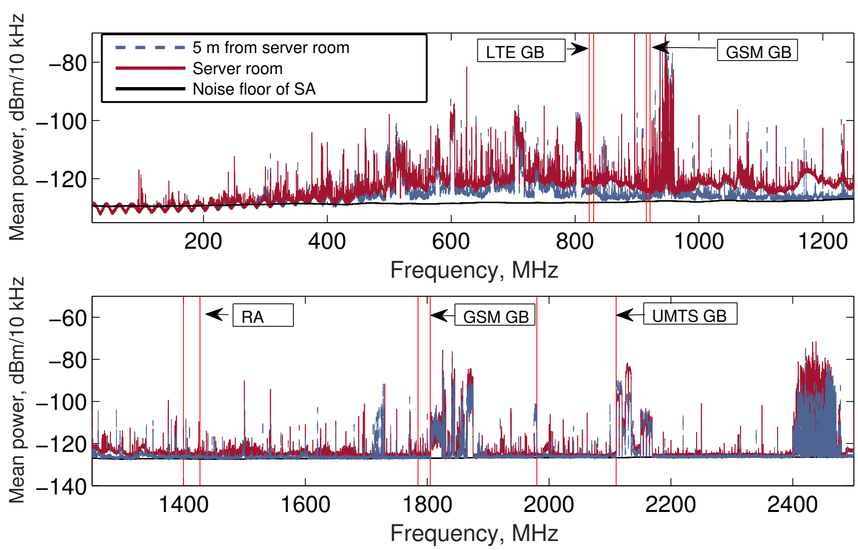


Fig. 6: Server room measurements from a small computational data center.

Question 3: Is there quantitative evidence of the overall increase in the total integrated noise floor across various segments of the radio frequency spectrum?

We note that this is not a straightforward question to answer. We have to separate the issue of the level of overall noise floor, and possible "noise problem". As mentioned previously, the "problem" is a more nuanced issue as the increase of digital transmission techniques means also that noise immunity characteristics have changed tremendously.

Available data from the past & references

There are both academic and governmental studies available from the past 20 years, and many of these provide high value (we list below some, but it is not an exhaustive bibliography).

However, we note to the TAC that one has to be careful on interpreting especially the older literature. This is due to the fact that modern (digital) wireless systems are technically highly different and the density of equipment is significantly higher than in the older studies. A simple extrapolation from earlier results is not guaranteed to provide meaningful results.

Moreover, we note that the inquiry refers to the "data". Although we understand that this primarily refers just to the evidence through the existing published results and measurements, we draw the attention of TAC to important issue of "raw data". To the best of our knowledge, raw measurement data is not available from any of the previous studies. In order to enable later comparisons and to encourage the transparency and wider data dissemination for research purposes, we believe that in the future the availability of some of the raw data should be ensured.

Finally, we note that comparing historical data from highly different environment has limited (although not insignificant) value due to the above-mentioned spatial variations.

With the above comments we can cite that there are publicly available and published results spanning the last 20 years or so, although the literature is not very wide – and we note that a lot of work is focused on lower UHF/VHF bands. The relevant publications for the TAC to consider would include; Achatz & Dalke [5], Chandra [8], ITU-R-P372 [7], Blackard [6], Chang & Lin [9] and some of our own recent work from a European perspective [1], [2], [3].

At what level does the noise floor cause harmful interference?

This is a very wide question, and we defer to comment it in any detail. We note that the harm of noise interference is a receiver issue and cannot be answered in a technology-neutral manner. As we have mentioned earlier, and commented in some of our publications, we fully expect that not only GPS-type of systems, but even cellular system can be harmed even with a relatively low increase of noise floor levels; or at least such information should be taken into account when designing future receivers.

Question 4: How should the noise study be performed?

Given the fact that there is little current data and even historical information is limited and sometime contradictory, it seems prudent to conduct new, high quality noise floor studies. Our own preliminary work certainly indicates this to be an interesting domain, and that the noise floor today has a very rich, and sometimes surprising spatiotemporal structure.

Any scientifically justified study has to consider its aim. Thus one cannot recommend any very specific rules for the noise study without TAC, or other entities, clearly stating what is the goal of such a study. However, we venture to make a few general comments:

1. The studies should be done by using high accuracy and sensitivity measurement equipment. We do **not** believe that using crowd-sourcing or low-cost equipment, or even non-calibrated software defined radios, would yield results that can be safely used to draw regulatory conclusions or significant recommendations towards industry.
2. The studies need to be done with sufficient geographical and temporal variety, and must include qualitatively different localities.
3. The studies should cover a number of different frequency bands, particularly below 6 GHz bands. The unused guard and "gap" bands are prime frequency areas for studies, but one should also consider conducting studies in a Public-Private partnership to study the situation in licensed bands; although this will be logistically more difficult, it can be achieved, and can lead to highly interesting results.
4. Statistically significant conclusions require a substantial amount of data, and also reporting statistics should be carefully discussed before launching any large-scale campaigns.
5. While we believe that academia can contribute a lot to such noise studies, our current assumptions is that public bodies (such as national research laboratories or institutes) might be the best positioned for measurements or at least coordinating them. Ideally there should be also support coming from the stakeholder industry for such studies.
6. We emphasize the need to also collect and store raw measurement data for future use.
7. One key issue is also that in noise measurements the limiting factor is not only the sensitivity of equipment, but one also needs high time-resolution capability to monitor noise as a sequence of pulses.

Finally, we clarify our position on who should be making measurements as follows. While any competent bodies, e.g. from academia, industry, or governmental entities, are able to make noise floor measurements with sufficient funding, we believe that the scale of the measurements, the need to store a large amount of data for a long period of time, and the time-scale required to collect data with equivalent equipment hints towards the situation that stable, governmental laboratories could be best suited to conduct a large part of the measurements or at least to coordinate them closely. This does not exclude the possibility that other parties, such universities or industry, could not also conduct and support some of these measurement campaigns. This recommendation is naturally partially based on our limited perspective on the situation in the USA, but this would be certainly our recommendation in the European context.

References

1. A. Palaios, M. Vanya, J. Riihijärvi, and P. Mähönen, "Understanding Current Background Noise Characteristics: Frequency and Time Domain Measurements of Noise on Multiple Locations." in *Cognitive Radio Oriented Wireless Networks and Communications (CROWNCOM), 2016*.
2. A. Palaios, V. Miteva, and P. Mähönen, "Man-made interference in below 3 GHz frequencies: How severe is the problem?" in *European Conference on Antennas and Propagation (EuCAP)*, April 2016, pp. 1–4.
3. A. Palaios, M. Vanya, J. Riihijärvi, and P. Mähönen, "When the whispers become noise: A contemporary look at radio noise levels," in *IEEE Wireless Communications and Networking Conference*, April 2016, pp. 1–7.
4. A. Wagstaff and N. Merricks, "Man-made noise measurement programme," *IEE Proceedings - Communications*, vol. 152, no. 3, pp. 371–377, June 2005.
5. R. J. Achatz and R. Dalke, "VHF space-to-Earth radio link performance in various man-made noise environments," in *IEEE Radio and Wireless Conference, 1998*, Aug 1998, pp. 257–260.
6. K. L. Blackard, T. S. Rappaport, and C. W. Bostian, "Radio frequency noise measurements and models for indoor wireless communications at 918 MHz, 2.44 GHz, and 4.0 GHz," in *IEEE International Conference on Communications*, Jun 1991, pp. 28–32 vol.1.
7. International Telecommunication Union, Radio Communication Sector, "Recommendation ITU-R P.372-12 Radio Noise," ITU-R, Tech. Rep., May 2015.
8. P. Chandra, "Measurements of radio impulsive noise from various sources in an indoor environment at 900 MHz and 1800 MHz," in *The 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, vol. 2, Sept 2002, pp. 639–643 vol.2.
9. M.-H. Chang and K.-H. Lin, "A comparative investigation on urban radio noise at several specific measured areas and its applications for communications," *Broadcasting, IEEE Transactions on*, vol. 50, no. 3, pp. 233–243, Sept 2004.